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UPCONVERSION WITH NOISE CONSTRAINED DIAGONAL ENHANCEMENT

Background of the Invention

1. Technical Field

This invention relates to the field of upconverting interlaced video to progressive (non-interlaced) video. More particularly, this invention relates to the field of deinterlacing algorithms.

2. Description of Related Art

When converting interlaced video to progressive scan format, a deinterlacing algorithm typically uses a temporal estimate (inter-field) in areas where no motion is detected, but uses a spatial estimate (intra-field) in motion areas. Spatial interpolation is used to generate an estimate for a missing line, based on the line above and below in the same field.

A simple method of deinterlacing a field of luminance pixels to create lines of pixels that are spatially in between the existing lines of the field is to average the values of the pixel directly above and below to create each new pixel. However, this method produces jagged edges on diagonal details in the field, such as on steps that are not horizontal or the on edges of the stripes on a flag as it waves in the wind and the angles vary.

A better method for enhanced diagonal detail, chooses between three pixel averages: the vertical average previously described and a left and right diagonal average. The left diagonal average is computed by averaging the value of the pixel to the left and above the position being interpolated with the pixel to the right and below. Likewise, the right diagonal is the average of the pixel to the right and above with the pixel to the left and below.

The basic idea of selecting between two diagonal averages and a vertical average was explored by the Sarnoff Research Laboratories (Sarnoff) in a research project funded by Thomson (assignee herein) in the early 1990's. The simplest algorithm choosing between the three choices was denoted in their report as the DIAG1 algorithm.

A simple algorithm to select one of these three averages was evaluated by Sarnoff and denoted DIAG1. The DIAG1 algorithm for selecting between two diagonal averages and a vertical average computes and compares three differences using the same pixel values as the averages. For each average, the corresponding difference is computed and the absolute values of those differences

are compared to find a minimum. The pixel average that corresponds to the minimum difference is selected to be the interpolated value.

The Sarnoff work mentioned is documented in two reports: Spatially-Adaptive De-Interlacing Techniques for Digital Feature TV, December 31, 1990 and Digital Feature TV Project Final Report, March 31, 1991.

Even with the apparent advantage of having multiple choices to consider for a spatial interpolation estimate, the existing decision process of DIAG1 appears somewhat random and noisy because the minimum value is not always the best choice. There is a long-felt need for an improved decision process that is relatively simple and inexpensive to implement, but nevertheless is less random and noisy.

Summary of the Invention

In accordance with the inventive arrangements, a noise constraint is added to the decision process of selecting between two diagonal averages and the vertical average, advantageously improving the picture quality in the areas where diagonal detail exists. This noise constraint causes the new algorithm, denoted DIAG1T, to prefer the vertical average in ambiguous cases.

More particularly, the DIAG1T algorithm advantageously prefers the vertical average under two conditions, representing further decision steps in addition to the DIAG1 average selection algorithm. Firstly, if the minimum difference is not unique, the vertical average is selected. Secondly, if the selected average does not lie in the range of values between the pixel above and the pixel below the position being interpolated, then the vertical average is selected.

The diagonal adjacent pixels line-up at angles in the displayed picture that correspond or depend upon on the sample rate. For a 720x480 picture with 4x3 aspect ratio, for example, the diagonals correspond to angles of about 41 degrees above horizontal. The improved algorithm can improve diagonal features in the picture that are steeper than this angle.

Brief Description of the Drawings

Figure 1 is a block diagram of the DIAG1T diagonal enhancement upconversion system in accordance with the present invention.

Figure 2 is a diagram useful for explaining the spatial orientation of original and interpolated pixels.

Figure 3 is a block diagram illustrating the details of the Averaging and Difference (AVG-DIF) blocks in Figure 1.

Figure 4 is a block diagram illustrating the signal flow in the DIAG1T circuit shown in Figure 1.

Figure 5 is a block diagram of the DIAG1 decision logic shown in Figure 4.

Figure 6 is a block diagram illustrating the DIAG1T constraint logic in Figure 4.

Detailed Description of the Preferred Embodiments

The deinterlacing algorithm in accordance with the inventive arrangements is denoted herein as the DIAG1T. The DIAG1T deinterlacing algorithm can be used as a spatial only (intra-field) algorithm or as a spatial estimate in a motion adaptive deinterlacing algorithm. The improvement achieved by the DIAG1T algorithm, when used for the spatial estimate instead of a simple line average, is significant.

In the following description, it is assumed that the video signal is in component form and that only the luminance component is processed with the DIAG1T algorithm. Thus, a "luminance pixel value" or "pixel value" as used herein refers to the luminance component. A simple line average is satisfactory for deinterlacing the two lower resolution chrominance components.

Let the luminance pixel values on two consecutive lines of input video be labeled Xij and the interpolated progressive output line pixels be labeled Yij as follows, and as shown in Figure 2:

Input line 1: X11 X12 X13 X14 X15
Output line: Y11 Y12 Y13 Y14 Y15
Input line 2: X21 X22 X23 X24 X25

A simple line average spatial estimate would be:

Y1j = (X1j + X2j)/2.

The description of the DIAG1T algorithm given below will focus on computing the spatial estimate for the output position Y13. For other output pixels, the pixel indices in the description would be adjusted accordingly. An implementation of the algorithm can choose to modify the processing described herein at the beginnings and ends of lines when required pixels are not available.

For Y13, the DIAG1T algorithm computes 3 pixel averages and 3 pixel differences as follows, and as shown in Figure 1:

y1L = (X12 + X24)/2;   d1L = abs(X12 - X24);

$y1V = (X13 + X23)/2;$ $d1V = abs(X13 - X23);$

$y1R = (X14 + X22)/2;$ $d1R = abs(X14 - X22);$

These averages and differences correspond to a left diagonal, a vertical and a right diagonal estimate. An exemplary block diagram of a circuit 10 for providing all these averages and differences is shown in Figure 1 including a plurality of delay circuits 12, 14, 16, 18, and 20 in the form of flip flops and other suitable devices. For example, delay circuit 16 can be a line delay. The circuit further includes minimum circuit 22, maximum circuit 24, as well as AVG-DIFF blocks 26, 28 and 30. The details of an exemplary AVG-DIF block such as the AVG-DIF block 26 in Figure 1 is shown in Figure 3. AVG-DIF block 26 preferably includes in an averaging portion of the device or block, a summer 34 for adding adjacent pixel values and a divide-by-two circuit 38. In a difference portion, block 26 further includes a subtractor 26 and an absolute value function 39.

The basic DIAG1 algorithm chooses the estimate that corresponds to the minimum difference as follows, and as shown in Figure 5:

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y=y1V;      d=d1V;
if (d1L<d) { y=y1L; d=d1L;}
if(d1R<d)  y=y1R;
Y13=y;
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More specifically, the basic DIAG1 decision logic 42 can be represented using comparators 52 and 58 and multiplexers 54, 56 and 59 coupled as shown in Figure 5 to provide the functionality of the DIAG1 algorithm described above, although the present invention is not limited thereto. Note that the DIAG1 algorithm or DIAG1 decision logic 42 forms a part of the overall DIAG1T decision logic 32 shown in Figures 1 and 4.

The noise constraint or the DIAG1T constraint logic 44 shown in Figures 4 and 6 that is used to clean up decision noise in DIAG1, and in so doing distinguish DIAG1T over DIAG1, further insists that a value for the given output pixel (Y13) fall within a range of values of a top pixel and a bottom pixel defining the vertical average for the given output pixel. In terms of equations, this means that either:

$$X13 \leq Y13 \leq X23 \quad \text{or} \quad X13 \geq Y13 \geq X23$$

If this constraint is not satisfied, then output $Y13 = y1V$.

An additional constraint distinguishing DIAG1T is that the left diagonal difference either equals or substantially equals the right diagonal difference. In other words, the differences for the left diagonally adjacent pixels and the right diagonally adjacent pixels need to be unique or d1R must differ from d1L. In terms of equations:

if $d1L = d1R$, then output $Y13 = y1V$.

These further constraints are illustrated in Figures 4 and 6. In particular, the DIAG1T constraint logic 44 shown in Figure 6 can be embodied by comparators 60, 62, and 64, OR gate 66 and multiplexer 68 arranged and coupled as shown to provide the functions described above.

Thomson's Princeton Engine real time digital video simulator was programmed to demonstrate Sarnoff's DIAG1, DIAG3 and DIAG3W deinterlacing algorithms and Thomson's new DIAG1T deinterlacing algorithm. The Princeton Engine was programmed to perform each DIAG algorithm as a spatial only (intra-field) deinterlacer and also as the spatial estimate of a motion adaptive deinterlacing algorithm.

The algorithms were simulated and demonstrated to various observers first with a fixed test pattern, the frame rate sweep, and then with frozen video scenes and finally with real time motion video.

In a frame rate sweep test pattern, a wide variety of horizontal, vertical and diagonal frequencies exist. All of the Sarnoff deinterlacing algorithms cause the deinterlaced test pattern to appear to have various regions defined by visible boundaries where some regions were estimated by the vertical average, and other regions by the left or right diagonal average. The main observable difference between the four algorithms DIAG1, DIAG3, DIAG3W and DIAG1T is the nature of the boundaries between the regions. When the frame rate sweep pattern is digitally generated, the boundaries are very clean and straight. However, when the test pattern is from an analog source with some noise, the boundaries are less well defined and jagged. With DIAG3W and DIAG1T the boundaries are noticeably cleaner. DIAG3 provides some improvement over DIAG1. There is little difference between the appearance of DIAG3W and DIAG1T but the DIAG1T algorithm is much less complex and much easier to implement than DIAG3W. The

region boundaries are significantly cleaner with the DIAG1T algorithm than with the DIAG1 algorithm.

In simulations with frozen or moving video, areas with diagonal detail are visibly improved. One such scene observed had an American flag waving in the wind. The stripes on the flag change from horizontal to various angles of diagonal as the flag moves in the wind and had visibly improved detail in such areas with diagonal detail. The improvement of jagged edges on some of the diagonal angles was significant.

When used as the spatial estimate of a motion adaptive algorithm, the DIAG1T algorithm significantly improves moving areas of the picture without significantly adding complexity or cost. Stationary regions of the picture already have superior detail from adjacent fields of the video.

In light of the foregoing description of the invention, it should be recognized that the present invention can be realized in hardware, software, or a combination of hardware and software. A method of interpolating a given output pixel value when upconverting interlaced video to progressive video according to the present invention can be realized in a centralized fashion in one processing system, or in a distributed fashion where different elements are spread across several interconnected systems. Any kind of computer system, or other apparatus adapted for carrying out the methods described herein, is suited. A typical combination of hardware and software could be a general purpose computer processor or digital signal processor with a computer program that, when being loaded and executed, controls the computer system such that it carries out the methods described herein.

The present invention can also be embedded in a computer program product, which comprises all the features enabling the implementation of the methods described herein, and which, when loaded in a computer system, is able to carry out these methods. Computer program or application in the present context means any expression, in any language, code or notation, of a set of instructions intended to cause a system having an information processing capability to perform a particular function either directly or after either or both of the following a) conversion to another language, code or notation; b) reproduction in a different material form.

Additionally, the description above is intended by way of example only and is not intended to limit the present invention in any way, except as set forth in the following claims.